DIFFERENTIATION OF KEWEENAWAN DIABASES IN THE VICINITY OF LAKE NIPIGON

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In recent numbers of *Economic Geology* two papers have been published describing the differentiation products of the quartz-diabases of the Nipissing District, Ontario.[1] Since these diabases have generally been regarded as of Keweenawan age, certain differentiation products of the Keweenawan diabases in the vicinity of Lake Nipigon are also of interest.

On the north shore of Lake Superior and extending northward beyond Lake Nipigon there are masses of diabase and gabbro which intrude the older crystalline rocks in the form of batholiths, dikes, and bosses and the sediments in the form of the "Logan sills." Although there are differences of opinion regarding the geological age of these rocks, the writer concurs with those who regard, as closely related in origin, the great amygdaloidal basalt flows of Keweenaw Point, the Duluth gabbro, the "Logan sills," the Sudbury Nickel eruptive, and the Cobalt diabases, as well as many other masses of diabase in intervening areas. The great igneous activity of this region seems to have been the result of extensive crustal adjustment centered around Lake Superior and diminishing in intensity as a greater distance from the center was reached. It is probable that on the northern side of the Lake Superior basin the intrusive masses were being injected into sediments which had already been formed while the alternate deposits of sediments and lava flows were being deposited on the south side and that a close relationship exists between all portions of this great series of sediments and extrusive and intrusive igneous rocks.

While a general description of the petrography of these rocks is given here, the object of this paper is to call attention to certain

[1] W. H. Collins, *Econ. Geology*, V, No. 6, p. 538; R. E. Hore, *ibid.*, VI, No. 1, p. 51.

evidences of differentiation which have already been mentioned by Dr. A. P. Coleman and the writer and to add additional notes to the descriptions of this phenomenon.

PETROGRAPHY OF THE DIABASES

The Keweenawan rocks around Lake Superior have been described petrographically in detail, by Irving, Bayley, Van Hise, and many others. In the vicinity of Lake Nipigon the rocks are in many respects similar to those around Lake Superior and they have been described with less detail by Coleman, Wilson, and other geologists. The greater portion of the shores and the islands of this lake consist of basic rock, either diabase or gabbro. Thin sections almost invariably show the ophitic texture more or less well developed, and, although in many places the diabase grades toward gabbro, the greater portion of the rock is diabase. In the sills, diabase always seems to be found, and the same statement may be made of the smaller bodies of the rock, while some of the larger batholithic masses, which have suffered some differentiation, more strongly resemble gabbro.

Structurally the rocks form bosses, large and small, batholiths, or very large irregular masses, dikes, and sills. The dikes are often large, as some were seen in the Onaman Iron Range area 150 ft. in width, and these seem to represent offshoots from the main diabase mass in the vicinity of the lake. The sills, known as the "Logan sills," form beds from two to several hundred feet in thickness. These masses lie between beds of sandstone, shale, or dolomitic limestone, or between these sediments and the underlying Archean rocks, and in all cases studied they present evidence of their intrusive character. Columnar structure is a characteristic of nearly all of the larger masses, especially of the larger sills.

In macroscopical characters these basic rocks generally present a monotonous appearance. They vary in grain from coarse to medium fine and in color from brownish to nearly black. Some of them weather rapidly to granular incoherent masses, and, in the early stages of this weathering, they exhibit in many places cleavage surfaces with a bronze tint. In many cases the ophitic texture is readily recognized in the hand specimen, but in the masses

which tend to become coarse grained and to separate into little aggregations of feldspar and magnetite this texture is lost to a large extent and the rock becomes more like a coarse gabbro. In one place on the shore of Lake Nipigon some sand was collected which showed poikilitic texture where feldspars were inclosed in augite.

In microscopical observations these rocks usually show labradorite, augite, or diopside, and ilmenite or magnetite. Olivine is widespread but is not always present and in specimens without olivine quartz has been found, but it is lacking in many specimens. Biotite appears in small quantities and titanite was found in one section. Since the latter mineral occurs near a dike of acid rock and is not commonly developed in diabases or gabbro, it is believed to be due to the influence of this dike, as some of these acid dikes carry titanite.

Although these rocks are on the whole comparatively fresh, certain alteration products occur. The olivine frequently shows serpentine and iron oxide as alteration products, and the augite and diopside, although usually quite fresh, often contain secondary amphiboles and actinolite. In a specimen from "Haystack Mountain," north of Lake Nipigon, a crystal of magnetite occurs partially surrounded by a mass of actinolite needles which, on revolving the stage of the microscope, show rotary extinction (Fig. 1). These needles seem to be the product of alteration of an augite crystal whose growth began around the magnetite and they resemble similar fibrous growths which W. S. Bayley describes as occurring around magnetite in the basic rocks of the Lake Superior region, although he does not ascribe a secondary origin to them.[1] In a specimen from the shore of Lake Nipigon, opposite "Two Mountain" Island, the diopside and magnetite are intergrown to some extent and the latter sometimes occurs as a fringe along the border of crystals of the former. Although much of the magnetite associated with the

FIG. 1.—Magnetite partially surrounded by augite which has altered to actinolite needles (greatly enlarged).

[1] *Journal of Geology*, I, 702–10.

diopside is primary, some crystals of the diopside which are partially altered to secondary amphiboles contain also undoubted evidence of alteration to magnetite and hematite. While these are unusual alteration products for diopside, analyses of this mineral from gabbro sometimes show as much as 15 per cent of

FIG. 2.—Photomicrograph of diabase showing ophitic texture (crossed nicols; ×40).

iron oxide. The pyroxene is readily recognized as diopside by its characteristic color and extinction angles.

In texture the ophitic character is usually well developed, as the labradorite generally occurs as lath-shaped, nearly euhedral crystals, which penetrate the augite and diopside (Fig. 2) and in some cases are surrounded by them, giving also a poikilitic texture. The rock might therefore be called, to apply the term suggested

by A. N. Winchell for such textures, a poikilophitic rock.[1] In sections of diabase from "Haystack Mountain" the augite is frequently twinned with two members, and instead of the usual stout crystal it occurs in long, narrow forms, somewhat lath shaped, and in this respect resembling the feldspars.

DIFFERENTIATION PRODUCTS; PEGMATITE DIKES

The differentiation products of the Keweenawan rocks of the Lake Superior region have been frequently mentioned. Clements states that the gabbro in Minnesota shows undoubted evidence of differentiation in the large masses of anorthosite and the patches of magnetite and titaniferous iron ore.[2] W. S. Bayley describes peridotites and pyroxenites as very basic phases of the gabbro in his description of the Lake Superior region.[3]

From Lake Nipigon A. P. Coleman describes picrite and other very basic phases of the diabase and also certain acid dikes which are described as post-Keweenawan but closely related to the Keweenawan basic rocks and perhaps differentiation products of them.[4] These rocks are described as having a pegmatitic or micropegmatitic texture and as having the composition of granite or granodiorite.

In "Haystack Mountain" north of Lake Nipigon the writer found similar dikes and from their relationships suggested that they represented an acid phase of the diabase magma.[5] The later observation of similar dikes in the Duluth gabbro near Duluth, Minnesota, confirmed the belief that these rocks are differentiation products of the diabases and gabbros.

The rock at "Haystack Mountain" is a coarse diabase, rather gabbro-like, and shows small, dark patches of titaniferous magnetite and in places lighter blotches consisting largely of feldspar. The magnetite is sufficiently abundant in part of the hill to influence the compass so that prospectors were led to record mining claims

[1] "Use of 'Ophitic' and Related Terms in Petrography," *Bull. Geol. Soc. Am.*, XX (1910), 661–67.

[2] *U.S. Geol. Survey, Monograph XLV*, 397–424.

[3] *Jour. of Geology*, II (1894), 814–25.

[4] *Bureau of Mines of Ontario*, XVII (1908), 163–64.

[5] *Ibid.*, XVIII (1907), 162.

upon it. Besides these small segregations of feldspar there are irregular dike-like masses of similar, light-colored rock and a few fairly distinct dikes, all of small size and varying from one-half inch to a foot in width. These dikes are rather fine grained and in thin section show the following characters. The texture is usually micropegmatitic and one section is composed of about 60 per cent feldspar, 30 per cent quartz, 10 per cent hornblende, and a little magnetite and hematite. The feldspar is chiefly orthoclase with a little albite and the rock is a granite. Another section contains very little hornblende and a little epidote, the rock being composed almost entirely of feldspar in the proportions of 65 parts orthoclase to 35 parts plagioclase. This rock is a syenite grading toward a monzonite. Still another section is from a dike which might be regarded as a monzonite. It contains a little enstatite, epidote, and titanite, while the greater portion of the rock is feldspar and in the proportions of about 66 per cent albite and oligoclase and 34 per cent orthoclase. A fourth section is from an augite-syenite dike in which the orthoclase makes up 75 per cent and the sodic variety 25 per cent of the feldspar. There are a good many small augite crystals and the micropegmatitic texture is well developed. A section of a dike from near "Two Mountain" Island is also an augite-syenite.

The most interesting dikes in the region are those occurring on Flat Rock Portage near the south end of Lake Nipigon. At this point a large mass of rock, described by Coleman as a sill of epi-basalt or fine-grained diabase-porphyrite, is cut by a pegmatite dike varying in width from three inches to one foot. Where the diabase has suffered columnar jointing the fissures have filled with acid rock similar to the flesh-colored or pink dikes described above (Fig. 4). The surface of this sill is flat and fine grained, and when the glacier passed over it interesting chatter-marks were left. The pegmatite dike is medium coarse grained, flesh colored, and appears to be composed very largely of feldspar. Under the microscope the pegmatitic intergrowth of various minerals and the graphic intergrowth of quartz and feldspar are well developed. The rock consists of quartz in proportion of 10 per cent, epidote 10 per cent, and sodium-calcium feldspar 80 per cent. The

feldspars show a wonderful development of the zonal structure (Fig. 3). In the rapid growth of the crystals the zones of calcium- and sodium-rich material have developed mostly at their ends, and they have thus been drawn out to excessive linear proportions. The indices of refraction indicate that the most calcic feldspars form the central zone and the more sodic follow outward. The usual order of rate of weathering of the sodic and calcic feld-

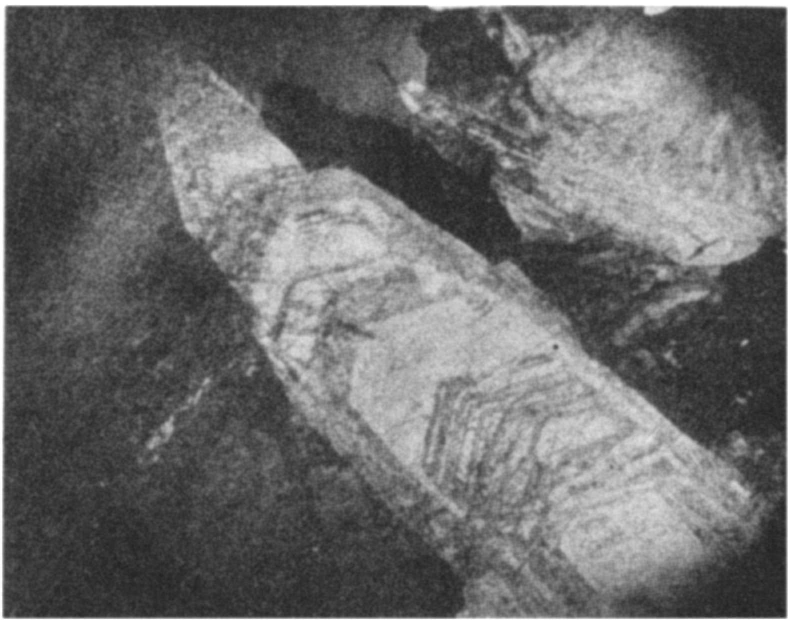

FIG. 3.—Photomicrograph of a section from a pegmatite dike at Flat Rock Portage showing unusual development of zonal structure in sodium-calcium feldspar (crossed nicols; ×40).

spars does not hold in many of these crystals, as the second zone even with lower index of refraction often shows much more extensive alteration than the central zone. The alteration products are epidote and a mineral or mixture of minerals which has yellowish polarization colors and is believed to be epidote, kaolin, and zeolites. A peculiar influence of the pegmatitic intergrowth of the minerals is the crystallization of epidote in some of the zones

replacing the feldspar. This arrangement was seen where the path of an epidote crystal was cut across by that of the growing, zonally built feldspar. In a couple of cases a group of epidote crystals is crossed by feldspar, but the simultaneous extinction of all parts of the epidotes shows them to be parts of the same crystal and in one case particularly a portion of the epidote crystal has passed through the feldspar, forming one of the zones of the crystal. In these cases the epidote is undoubtedly primary, although considerable secondary epidote occurs from alteration of the feldspars.

An interesting example of a crushed feldspar is seen in this section where the crystal has been broken into slivers and the fragments surrounded by quartz. This must have been due to pressure, although the rock as a whole does not show evidence of excessive pressure beyond the undulatory extinction of some of the quartz grains.

In his description of the copper-bearing rocks of Lake Superior, Irving describes some sections from dikes of red rock in the Duluth gabbro which would indicate that they are probably similar to those dikes described above.[1]

These acid dikes appear to be differentiation phases of the Keweenawan diabases and gabbros because they occur, with one exception, in these rocks only, and, so far as observed, only in the larger masses and not in the thin sills which are too small to produce them by differentiation. This one exception is a dike 30 inches wide cutting quartzite and the overlying diabase near Ombabika Narrows.[2] This dike might be due to the rising of the liquid from some large diabase mass below through a fissure extending into the overlying rocks. There are no other bodies of acid rock in the region later in age than the Keweenawan diabases, and the pegmatitic and micropegmatitic textures suggest end phases of a magma. These dikes probably fill crevices in the diabase formed in the solidified exterior of a large mass, due to adjustment of pressures during processes of cooling, and the acid material rose from the still hot and more acid lower portions of the mass. The fact that these dikes are so much more basic on the whole than

[1] *U.S. Geol Survey, Monograph V*, 119–20.

[2] Coleman, *Bureau of Mines of Ontario*, XVII, 164.

the aplites of the Cobalt area may be due to the fact that the magma from which they separated was on the whole more basic. The ophitic texture of the diabases indicates a magma early saturated with calcium. The alkalies, being in small quantity, were mostly left over until the end of the crystallization period and then united with the remaining aluminium and silica to form potassium or sodium feldspars, while the small excess of silica occurring in a few places

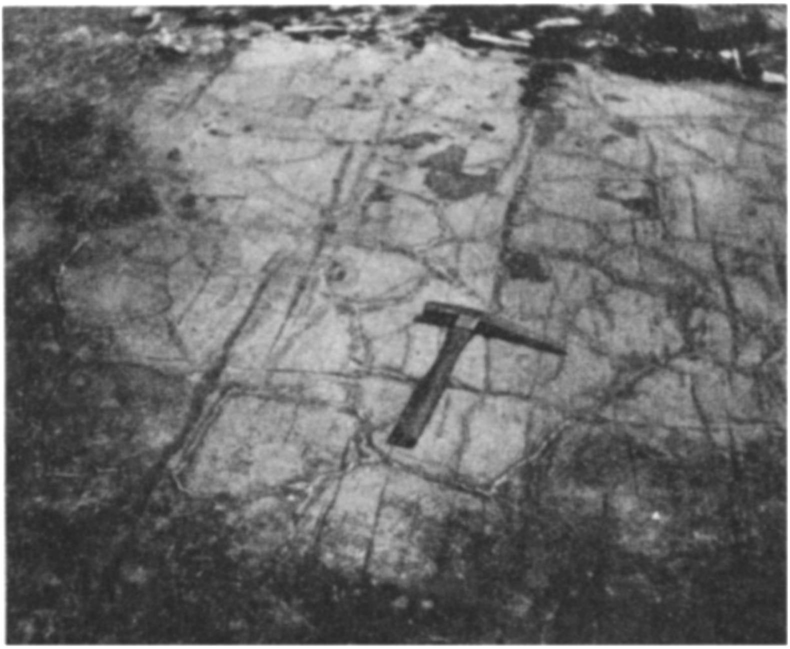

FIG. 4.—Acid dikes filling columnar joint fractures in diabase.

went to form quartz. It is thus assumed that the magma became saturated with the more basic materials first, and the remaining acid materials, still liquid, were in some cases crowded toward the lower and central portion of the mass to escape into the fissures when opened, and form dikes.

In the case of the pegmatite dike in which the feldspar is largely calcic and occurs with the silica, it is probable that the excess of magnesium and iron caused the rocks to become saturated with

these elements, and the augite and olivine, separating out earlier, caused some of the calcium and aluminium to be left over to enter the dike.

It is interesting to note that in the Sudbury and Cobalt areas, where the Keweenawan rocks have suffered very great differentiation compared with that in the Lake Nipigon region, there are extensive ore bodies connected with them, while there is nothing but a little iron ore in the Nipigon region, and this occurs at the contact with sediments and may be leached from them.

While differentiation of magmas and thus the separation of the metals, as well as other elements, from the magmas, may be only one factor in the development of mineral veins as well as magmatic segregations, it seems probable that all data collected on this subject will show this is one of the important factors. Other things being equal, if the igneous rocks are the source of the metals, those magmas which show the greatest differentiation should be the most favorable for the production of ores, whether they supply metal-bearing solutions directly to the veins—a process quite conceivable in some cases—or whether they cause segregation of the metals so that they can readily be dissolved by meteoric waters in sufficient quantities to form ore deposits in veins.